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NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

NAVY MISSION PLANNER

by

Kevin Dugan

September 2007

Thesis Advisor:
Second Reader:

W. Matthew Carlyle
Jeffrey Kline

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NAVY MISSION PLANNER

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

The United States Navy continually deals with the challenges involved with the assignment of limited resources to address numerous and dispersed critical missions. The Navy's continued pursuit of decision aids to answer this problem and the ongoing critical maritime operations in the western pacific and Arabian seas demonstrate the importance of this issue. How do navy staffs assign surface and subsurface combatants to areas and missions? The available ships may be inbound or outbound to the maritime theater, they may already be assigned to other missions in different regions, or may require transit and off station time before they can cover a particular mission. In planning major operations there are usually more missions than can be covered by available Navy combatants; therefore, it is likely that no ship will be assigned to low-priority missions, and deciding which higher-priority missions to cover at any time involves complicated tradeoffs. This planning problem is compounded by the fact that multiple alternatives are required by fleet commanders and Joint Force Maritime Component Commanders (JFMCCs) who want to maximize the effectiveness of their maritime forces while avoiding excessive risk and identifying gaps in mission coverage. This thesis develops a decision support tool, the Navy Mission Planner (NMP), which rapidly selects employment schedules for Navy combatants to meet the requirements above. We illustrate how NMP identifies optimal coverage of maritime missions in a theater with a notional, unclassified Korean peninsula scenario with 11 ships, 65 missions and 24 user defined maritime regions, on a desktop PC. NMP gives decision makers the ability to adjust courses of action by manipulating the time horizon, optimality criterion, mission values, mission dependencies, and ships available, and provides valuable insight into which missions will and, more importantly, will not be covered for any set of mission priorities.

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TABLE OF CONTENTS

I.	INTRODUCTION.....	1
A.	PURPOSE AND OVERVIEW.....	1
B.	BACKGROUND	2
1.	Problem Statement.....	2
2.	Missions, Regions and Concurrent Mission Capable Sets	3
3.	Maritime Missions	4
C.	HISTORY OF AUTOMATION	6
D.	SCOPE AND LIMITATIONS	7
E.	THESIS ORGANIZATION.....	8
II.	MARITIME PLANNING AND EXECUTION FOR THE JFMCC.....	9
A.	INTRODUCTION.....	9
B.	ROLE AND RESPONSIBILITY OF THE OPERATIONS CENTER	
(N3).....		9
1.	Future Operations Cell.....	10
2.	Operations Assessment Cell.....	10
III.	OPTIMIZATION MODEL FOR THE TASKING OF MARITIME ASSETS...13	
A.	INTRODUCTION.....	13
B.	AN INTEGER PROGRAM TO OPTIMIZE MARITIME MISSION	
ASSIGNMENTS: NMP		14
1.	Sets and Indices [cardinality].....	15
2.	Data [units]	15
3.	Variable [unit]	15
IV.	COMPUTATIONAL RESULTS.....	23
A.	TEST SCENARIO	23
B.	TEST RESULTS FOR NMP.....	24
V.	CONCLUSIONS AND RECOMMENDATIONS.....	27
A.	SUMMARY	27
B.	DIRECT OPERATIONAL APPLICATION	27
C.	OPERATIONAL INTRODUCTION.....	27
D.	FUTURE DEVELOPMENT.....	28
1.	Interface with the Common Operating Picture (TBMCS)	28
2.	Utilize NMP logic to Plan Fire Support	28
3.	Utilize NMP logic to Focus Marine Corps Distributed	
Operations Concept		28
4.	Constrained Enumeration of Feasible Employment Schedules.....	29
	LIST OF REFERENCES	31
	INITIAL DISTRIBUTION LIST	33

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LIST OF FIGURES

Figure 1.	JFMCC Operation Center Organization [TM 3-32-06]	9
Figure 2.	Future Operations Cell Organization [TM 3-32-06]	10
Figure 3.	Dashboard of NMP interface	22
Figure 4.	Korean Maritime Theater	24

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LIST OF TABLES

Table 1.	Example employment schedules for the USS Roosevelt with user defined effectiveness levels for active mission capabilities	18
Table 2.	Missions sheet of the NMP interface	19
Table 3.	Mission Dependencies in the NMP interface.....	20
Table 4.	Destroyer portion of the available ship list from the NMP interface.....	21
Table 5.	Concurrent mission capable sets for destroyers from the NMP interface	21
Table 6.	Selected Schedule for DDG 53 (USS John Paul Jones) for days 5 through 15.....	25
Table 7.	NMP log file mission accomplishment by day and by region.	26

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EXECUTIVE SUMMARY

Maritime operational planners continuously address the complex problems involved with the employment of Navy ships. The assignment of ships to missions must take into account ship capabilities, the time each ship is available in theater, distances and transit times between missions, and mission values. This complicated and multifaceted staff task has been accomplished up to this point largely through manual planning efforts.

In regards to the number of maritime missions and their geographic dispersion in any major operation, Navy ships continue to be in short supply. Surface and subsurface combatants are called upon to cover more missions and more geographic areas than is possible with ships that are available. Navy operational planners have addressed this problem successfully, but they have done so without the aid of an analytic decision support tool. They assign finite resources against requirements, but they have no way of rapidly developing multiple courses of action (COAs), quantifying the effectiveness of their plans, or evaluating the importance of the missions they have decided to leave uncovered.

Furthermore, risk mitigation adds complexities to the ship-to-mission assignment problem that further slows down the development of maritime plans. For example, a theater ballistic missile defense (TBMD) mission might be required in a certain region. The staff may need to assign another ship in the same area to conduct air defense to protect the TBMD platform. These *mission dependencies* are numerous, and can arise from considerations of mission type, geography, or time. Manually working through all of these constraints can quickly bog down a maritime staff's efforts. Developing or revising assignments for several Navy ships for any time horizon is a complicated, highly constrained optimization problem.

This thesis develops an automated, optimizing decision aid, the Navy Mission Planner (NMP), for the purpose of quickly developing COAs for the employment of Navy ships. It consists of an integer programming formulation of the ship-to-mission assignment problem, a link to a commercial solver that provides an optimal selection of

employment schedules from a (potentially huge) pool of feasible employment schedules, and a spreadsheet user interface that presents the relevant data in an easily-understood format that enables users to quickly change planning inputs. NMP can provide optimal results in seconds, and contains planner-controlled parameters that define (a) the planning time horizon, (b) the required solution quality (optimality gap), (c) a set of missions by region, their time horizon and value, (d) mission dependencies, and (e) a set of proposed employment schedules for each ship. Results highlight the employment schedules selected for each ship over the identified planning horizon and the mission coverage (or lack thereof) for each mission in the scenario. NMP is easy to use, and allows maritime planners to rapidly adjust and re-solve the model to suggest multiple COAs for further evaluation.

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Most of all I want to thank my family for the support and patience they have shown over the past two years. My wife, Ana, has been a wonderful mom to our daughter. My daughter, Emily, has been an absolute sweetheart. Coming home to her every day is something I always look forward to.

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I. INTRODUCTION

A. PURPOSE AND OVERVIEW

The complex and dispersed environment of maritime operations requires thorough and efficient planning and execution by the U.S. Navy to fulfill its requirements in support of a Joint Forces Commander for a major theater. In coordination with the other component commanders, the Joint Force Maritime Component Commander (JFMCC) conducts centralized maritime planning to carry out the difficult task of addressing maritime missions in an operational environment. Currently there is no operational level planning tool available for maritime multi-asset, multi-mission tasking. The JFMCC utilizes a largely manual process to develop the Master Maritime Attack Plan and Maritime Task Order based on incoming Maritime Support Requests and the available assets under his command. [Lockheed Martin, 2003] This process can quickly become ungainly as the number of mission requirements and assets increase. The problem is compounded by the JFMCC's need for (a) multiple Courses of Action (COAs) and (b) “maximum” mission coverage. This thesis develops an optimization model, the Navy Mission Planner (NMP), as an automated decision aid for the JFMCC to address these deficiencies.

NMP comprises a Microsoft Excel interface, an integer linear programming model, and Visual Basic for Applications (VBA) code to provide an interface between the two. Given a set of available U.S. Navy ships and a set of maritime missions in a theater of operations, NMP assists in COA development by matching required missions with multi-mission capable ships. It accomplishes this by considering mission values, ship capabilities and availability, and time-and-distance steaming requirements, and selecting an employment schedule for each available ship that maximizes the overall value of missions covered while ensuring critical mission interdependencies are obeyed. Multiple viable COAs can be developed quickly and easily to give the JFMCC the time and flexibility to effectively consider several force options for controlling the maritime environment.

B. BACKGROUND

1. Problem Statement

The Navy plans and executes operations very well, and it has done so for over 232 years, but has lagged behind its sister services in regards to computer-based operational planning and current operations management. In order to address this problem, this research formulates a mathematical programming model and uses optimization techniques proven effective in previous research done for planning theater ballistic missile defense [Diehl, 2004, Brown et al., 2005], revising an air tasking order in real time [Zacherl, 2006], and for routing logistics aircraft in a theater of operations [Bridges, 2006]. The model's specific goals will be to (1) identify the optimal set of employment schedules for each available ship in a given scenario, and (2) provide the planners a means to develop multiple COAs by changing values for the missions or including and excluding different ships or missions from subsequent runs of the program in order to plan for different phases of an operation. Our ultimate goal is to develop a decision aid that quickly provides a face-valid optimal solution.

Operational level planning for a theater of war is a complicated and time intensive endeavor for a component commander such as the Joint Forces Land Component Commander (JFLCC) or the Joint Forces Air Component Commander (JFACC). It is especially difficult for the JFMCC due to the nature of maritime missions and naval assets. Air missions seem ready made to plan, schedule, change and track quantifiable Measures of Effectiveness (MOE). A flight has a set start time and completion time, and tactical air strike missions last for minutes or hours. Maritime missions can not be packaged so neatly. A single tactical mission for a ship may continue indefinitely, and the ship may also be executing several missions simultaneously. A ship may also remain on station continuously for months and execute several missions of different types during this time. The pool of available ships in a theater will include (a) some that are already assigned one or more missions, (b) some that have recently arrived in theater and are awaiting missions and (c) some that are at the end of their deployments and are preparing to leave the theater. Because of these factors, naval planning is largely a manual effort.

The obvious drawback to manual planning is that a Navy operational planning staff can quickly become bogged down when the number of naval assets and the number of missions to address changes, even slightly. Planning can quickly become a purely reactionary exercise, and long-range plans can be abandoned by the planners because it is nearly impossible to keep up with changing situations during dynamic operations. It is clear that a quick and responsive automated decision aid is needed. This research will address this shortcoming by developing a user-friendly optimization program that will enable the JFMCC to quickly reconfigure the available ships in theater to cover required missions as the situation and priorities change over the course of a campaign. This will enable planners to continuously provide several viable maritime COAs to the JFMCC for any particular portion of a plan or actual campaign.

Depending on what Maritime Headquarters (MHQ) section will utilize this planning tool, time may or may not be constrained. Elements of the Maritime Future Plans Center will have much more time to produce the planning products required of them because they have to conduct more detailed and methodical analysis in their work. Future Plans is also not engaged in managing the current situation. In contrast to this, Future Operations (FOPS) has a much shorter period of time to produce their products, and Current Operations (COPS) has even less time. NMP appears to be well suited for each of these work sections, especially for FOPS.

2. Missions, Regions and Concurrent Mission Capable Sets

For clarity and problem formulation, this thesis defines the following data elements:

- **Mission:** A task or duty that requires one or more Navy ship combatants to be addressed or accomplished. This thesis deals with ten major mission areas covered in the previous definitions.
- **Region:** User defined areas of a maritime theater that are utilized to divide the JFMCC's area of responsibility into smaller areas for planning and coordination purposes. For example, this thesis utilizes a

Korean theater scenario, and has broken the maritime area into 24 rectangular regions of appropriate, but varying, sizes.

- **Concurrent Mission Capable Set:** A set of maritime missions, based on ship class, type that a U.S. Navy ship can execute simultaneously.

3. Maritime Missions

Many of the terms associated with naval operations and assets may mean different things to different organizations and military services. For the sake of clarity, this thesis uses ten standard *missions* to represent the possible taskings required in an operational plan, and applies the following twelve mission definitions (we define two extra “missions,” *transit* and *off-station*, each of which represents a state in which a ship is not accomplishing a specific mission tasking):

- **Air Defense (AD):** All defensive measures designed to destroy attacking enemy aircraft or missiles in the Earth’s envelope of atmosphere, or to nullify or reduce the effectiveness of such attack. [JP 1-02] This thesis separates air defense into two major mission areas. AD refers to air defense measures exclusive of Ballistic Missile Defense (BMD).
- **Joint Theater Missile Defense (JTMD):** The integration of joint force capabilities to destroy enemy theater missiles in flight or prior to launch or to otherwise disrupt the enemy’s theater missile operations through an appropriate mix of mutually supportive passive missile defense; active missile defense; attack operations; and supporting command, control, communications, computers, and intelligence measures. Enemy theater missiles are those that are aimed at targets outside the continental United States. [JP 1-02] We will refer to the Navy’s portion of this mission to defend against ballistic missiles as **TBMD**.

- **Strike:** An attack which is intended to inflict damage on, seize, or destroy an objective. [JP 1-02 U] Strike missions help shape the battlefield to support decisive operations or future maneuver. Joint and theater-level command and control, targeting, and combat assessment resources are required to support strike mission execution. [NWP 3-09.1 U]
- **Naval Surface Fire Support (NSFS):** Fire provided by Navy surface gun and missile systems in support of a unit or units. [JP 3-09.3] Fire support, in general, requires rapid decision-making time lines, the highest-fidelity battlefield pictures, and the shortest communication loop between maneuvering forces and fire-support assets. [NWP 3-09.1]
- **Maritime Interception Operations (MIO):** Efforts to monitor, query, and board merchant vessels in international waters to enforce sanctions against other nations such as those in support of United Nations Security Council Resolutions and/or prevent the transport of restricted goods. [JP 1-02] In this thesis, counter-special operations will be included in MIO mission assignments.
- **Mining:** Mining embraces all methods whereby naval mines are used to inflict damage on adversary shipping to hinder, disrupt, and deny adversary sea operations. Mines may be employed either offensively or defensively to restrict the movement of surface ships and submarines. [NWP 3-15]
- **Mine Countermeasures (MCM):** All offensive and defensive measures for countering a naval mine threat, including the prevention of adversary mine laying. [NWP 3-15]
- **Antisubmarine Warfare (ASW):** Operations conducted with the intention of denying the enemy the effective use of submarines. [JP 1-02 U]

- **Surface Warfare (SUW):** That portion of maritime warfare in which operations are conducted to destroy or neutralize enemy naval surface forces and merchant vessels. [JP 1-02 U]
- **Intelligence Collection:** In intelligence usage, the acquisition of information and the provision of this information to processing elements. [JP 1-02 U] For simplicity, this thesis will refer to this simply as **Intel**.
- **Transit:** The time, measured in days, required for a ship to travel from one region to another.
- **Off-station:** The disposition of a ship when it is in a region, but it is unavailable for any of the missions defined in this thesis. For example, a ship conducting underway replenishment would be considered off-station.

C. HISTORY OF AUTOMATION

The Navy has sought a tool to assist JFMCC operational level planning for several years. The need for centralized planning and the decentralized nature of executing naval operations presents unique problems to naval planners. A frequent "lesson learned" noted in exercises like Fleet Battle Experiment H (FBE H) / Millennium Challenge 2000 (MC 00), FBE-J/MC 02, the Multi Battle Group In-port Exercise (MBGIE) in February 2004, and others, is the requirement for an operational level maritime planning tool. Lockheed Martin attempted to address the planning need in 2002 and 2003 with the Maritime Asset Optimization Tool (MAOT). MAOT envisions pulling maritime support requests (MARSUPREQs), readiness information, ship location, asset capability and other pertinent information from the Global Command and Control System (GCCS), Status of Resources and Training System (SORTS) and various databases in order to develop Asset Task Assignment Suitability Scores (ATAS) for ships that are considered for particular missions [Prendergast 2003]. Overall cost and effectiveness scores are to be tabulated in order to assist the planners to identify the effective mission-

asset pairings. The Navy ultimately decided to not develop MAOT, so Lockheed Martin is not pursuing the optimization programming and other improvements required to make it a viable tool. However, the Navy is continuing to pursue centralized, automated planning tools in order to support the JFMCC. A current effort to provide a planning tool is again being developed by Lockheed Martin that utilizes the already fielded Theater Battle Management Core System (TBMCS) as an automated and net-centric planning tool that will better align navy planning with the joint environment. TBMCS may improve Navy efforts at continuous and dynamic planning, but it is currently not configured to utilize optimization to help produce JFMCC planning products. Instead, Lockheed Martin is currently trying to build the MTO with the current labels and fields already within TBMCS [Prendergast, 2007].

Our goal is to produce a viable decision aid for naval planners, but more specifically those naval officers and sailors who operate in the plans and future operations sections of a JFMCC headquarters.

D. SCOPE AND LIMITATIONS

The computational complexity of scheduling problems can make it quite difficult to solve our multiple ship, multiple mission employment problem. This thesis is limited to ten standard combat missions for ships and two non-combat missions, “transit” and “off-station.” Our model does not explicitly model logistics in support of combat operations, but can implicitly model its impact using the “off-station” mission. Our model plans operations at daily resolution; it would become far too complex if we were to schedule on a watch-by-watch basis.

Opportunities to test decision aids like NMP are limited. A realistic operational test will eventually have to take place in Fleet or JFMCC headquarters during a naval or joint exercise. Fleet or JFMCC level scenarios with a focus on surface and subsurface combatants would be appropriate. The duration of the scenario should be of sufficient length to have the planners deal with several ships arriving in a theater. The time could

then be divided into time horizons of ten to fifteen days. Employment of any number of surface and subsurface combatants is possible as long as complete employment schedules are provided for NMP to choose from.

E. THESIS ORGANIZATION

Chapter II provides a discussion of the Maritime Headquarters with Maritime Operations Center (MHQ-MOC) and its section(s) that would benefit most from the use of NMP. Chapter III describes the NMP optimization model. Chapter IV provides a notional, unclassified Korean peninsula test scenario, and a detailed analysis of the solutions provided by the NMP model for that scenario. Chapter V is devoted to conclusions and recommendations for future work involving NMP.

II. MARITIME PLANNING AND EXECUTION FOR THE JFMCC

A. INTRODUCTION

The JFMCC's role is to identify maritime objectives, plan in support of the Joint Force Commander (JFC), and conduct maritime operations. The JFMCC plans and executes JFC assigned missions by translating operational objectives and taskings into operational and tactical action by subordinate commanders. This chapter describes the JFMCC staff section(s) that would benefit from NMP.

B. ROLE AND RESPONSIBILITY OF THE OPERATIONS CENTER (N3)

The N3 is responsible for JFMCC operational level coordination, synchronization and guidance of near term planning and execution. [TM 3-23-06] Figure 1 summarizes the eight major work cells of the N3.

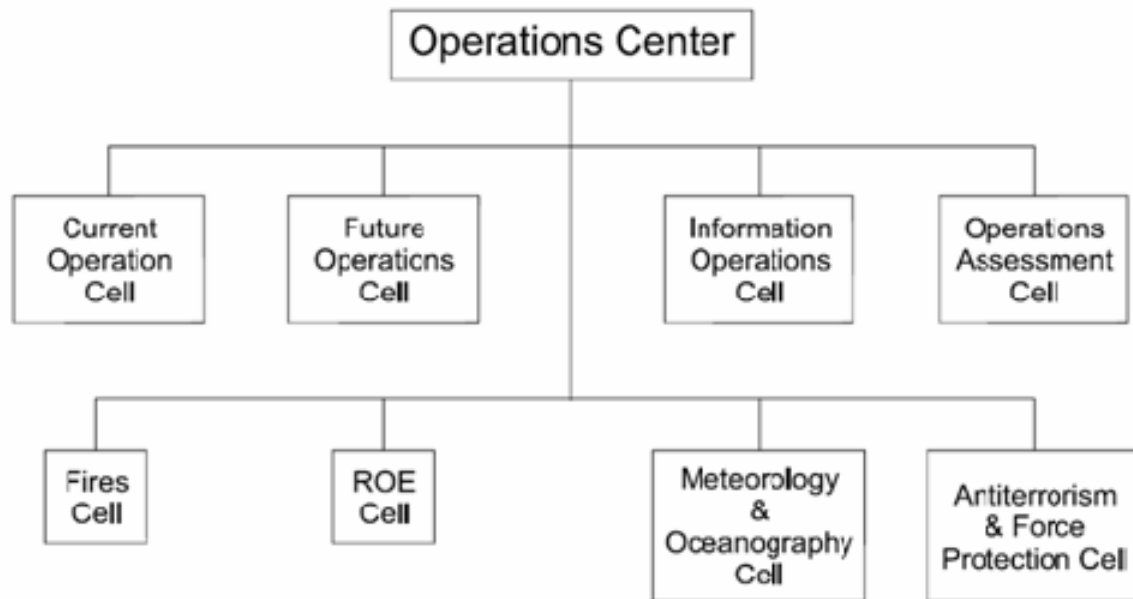


Figure 1. JFMCC Operation Center Organization [TM 3-32-06]

1. Future Operations Cell

The Future Operations (FOPS) cell translates the JFMCC's operational level guidance and objectives into tactical missions to be accomplished by subordinate commanders. [TM 3-32-06] As the central near-term planning coordinator for the JFMCC, FOPS serves as the bridge between theater and campaign plans and the execution of those plans. Anticipated or desired actions that require any analytical rigor, within the realm of the existing supporting plan, are staffed in FOPS. [TM 3-32-06] Organized into groups, experts in multiple areas of warfare continuously plan and prepare while they refine the products they send to the Current Operations (COPS) cell. These products include operational orders, fragmentary orders and periodic intentions messages. [TM 3-32-06] FOPS personnel must also communicate constantly with their COPS counterparts and liaison officers from subordinate commands to quickly and effectively identify, maritime component coordination gaps, conflicts and opportunities; then propose various courses of action (COA) as potential solutions. [TM 3-32-06] Currently FOPS does not have time or personnel to develop multiple COAs simultaneously. Figure 2 identifies a potential organization for FOPS.

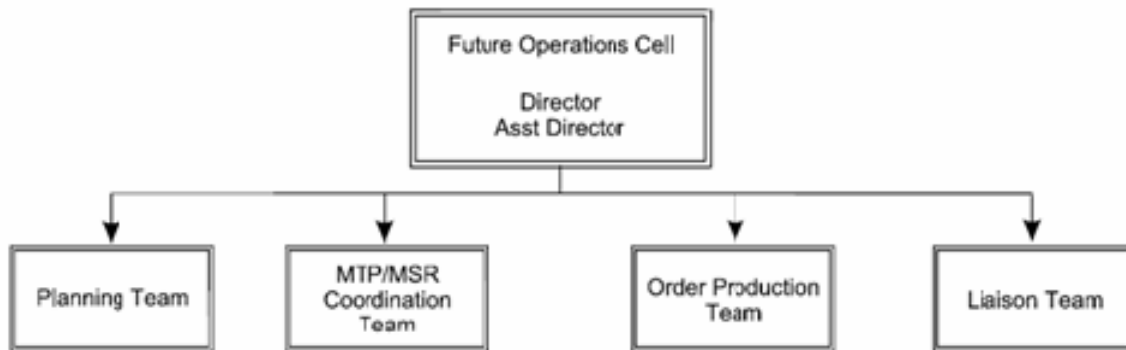


Figure 2. Future Operations Cell Organization [TM 3-32-06]

2. Operations Assessment Cell

Continually assessing the current situation and determining progress toward current goals is the responsibility of the Operations Assessment Cell (OAC). The OAC

facilitates the JFMCC's ability to adapt to changing circumstances and to exploit fleeting opportunities, respond to developing problems, modify schemes of maneuver, or redirect efforts. [3-32-06] By comparing the plan that was developed in FOPS with the actual operations and situation being managed by COPS, the OAC provides the JFMCC with estimate of the progress of an operation. The recognition that a difference exists between the plan and the actual situation is a catalyst for decision making [3-32-06]. Currently, reconfiguration of assets, missions, is time consuming and difficult. An automated decision support tool that can rapidly reevaluate new configurations would provide tremendous value to the OAC planning efforts.

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III. OPTIMIZATION MODEL FOR THE TASKING OF MARITIME ASSETS

A. INTRODUCTION

Employment scheduling is the process whereby U.S. Navy ships, submarines, aircraft and other units are assigned to major operations, exercises, maintenance periods, inspections and other events. [Brown et al., 1988] Assignment of a suboptimal mix of forces and capabilities to perform an operational mission or major exercise results degraded performance and, in the extreme, may result in failure to achieve the objectives of the mission or exercise. [Brown et al., 1988] This chapter formulates an integer linear program, called the Navy Mission Planner (NMP), as a set-partitioning integer linear program and applies it to the problem of determining an optimal employment schedule for each U.S. Navy combatant included in any scenario of interest.

NMP requires as input a list of available *ships*, a list of geographic *regions* for ships to occupy, a discrete set of *days* covering a finite time horizon (our planning is at daily resolution), a list of *missions* drawn from the ten maritime combatant missions primary missions defined above to be accomplished in each region on each day, with a *value* for each such mission that represents the benefit of fully accomplishing that mission, and a set of *mission dependencies*, each of which specifies, for a given mission in a given region on a given day, any other missions that are required to be *fully accomplished* in order to permit the given mission to be accomplished to any level.

For the purposes of this thesis, an *employment schedule* for a ship is a specification for each day in the planning horizon of (a) a single region in which the ship operates on that day and (b) a set of scalar *accomplishment* values, one for each mission that ship is capable of, that indicate what fractional amount of that mission that ship can accomplish on that day in that region. There are a potentially enormous number of feasible employment schedules for each ship. NMP requires as its final input a specification of a set of feasible employment schedules for each ship. An optimal solution to NMP is then a selection of one employment schedule for each ship that

maximizes the total value of covered maritime missions, while guaranteeing that all mission dependencies are respected. As a result of this optimal selection of employment schedules NMP also reveals the optimal set of missions to accomplish (fully or partially), and, therefore, which missions must remain uncovered. The solution selects a subset of the potential ship assignments that satisfies the logical requirements and maximizes the overall reward. The optimal objective function value will be the total of all mission values weighted by their total accomplishment among all ships available, and represents the optimal employment of the available navy ships based upon the user defined values of the missions. Clearly changes to these mission values can lead to a different set of optimal employment schedules. In some cases there are prerequisite missions that need to be covered in order for another mission to be covered too. For example, MIO might be required in a region by the shore, but AD in that region would have to be assigned to a ship before the MIO would be assigned.

The mission information required for NMP to execute these tasks is input into the interface. Missions are identified by region, time horizon, type and value on the 'Missions sheet. Any mission dependencies that are required are identified on the 'Mission Dependencies' sheet; these dependencies are defined region, time horizon, the dependent mission and its required mission.

B. AN INTEGER PROGRAM TO OPTIMIZE MARITIME MISSION ASSIGNMENTS: NMP

The following integer linear program, NMP, seeks the best achievable set of maritime mission-Navy ship pairings. After presenting the model, we will develop the detail required to compute its objective-function coefficients and generate instances of the model.

1. Sets and Indices [cardinality]

$s \in S$ Ships [~ 40]

$p \in P$ Employment schedules [~ 1 million]

$p_s \in P_s \subseteq P$ Employment schedules for ship s [\sim many]

$(\bigcup_s P_s \equiv P, P_s \text{ is a partition of } P.)$

$r \in R$ Regions [~ 30]

$d \in D$ Days [~ 14]

$m \in M$ Missions (alias m') [~ 10]

$n \in N$ Ordinal indicator for multiple missions [~ 5]

$L \subseteq M \times M \times R \times D$ Mission requirements: $(m, m', r, d) \in L$ if in region r on day

d mission m requires that mission m' be fully accomplished.

2. Data [units]

$value_{m,n,r,d}$ Priority of mission m , ordinal n , in region r on day d [1-10]

$accomplish_{m,r,d,p}$ Level of accomplishment of mission m in region r on day d
for schedule p [0.0-1.0]

3. Variable [unit]

$U_{m,n,r,d}$ Level of accomplishment of mission m , ordinal n ,
in region r on day d [0.0-1.0]

$V_{m,r,d}$ Mission m is fully accomplished in region r on day d [Binary]

Y_p Schedule p is used [Binary]

4. Formulation of NMP

$$\max \sum_{m,n,r,d} value_{m,n,r,d} U_{m,n,r,d} \quad (T0)$$

$$s.t. \sum_{p \in P_s} Y_p = 1 \quad \forall s \quad (T1)$$

$$\sum_n U_{m,n,r,d} \leq \sum_p accomplish_{m,r,d,p} Y_p \quad \forall m,r,d \quad (T2)$$

$$V_{m,r,d} \leq \sum_p accomplish_{m,r,d,p} Y_p \quad \forall m,r,d \quad (T3)$$

$$U_{m,n,r,d} \leq V_{m',r,d} \quad \forall (m,m',r,d) \in L, \forall n \quad (T4)$$

$$0 \leq U_{m,n,r,d} \leq 1 \quad \forall m,n,r,d \quad (T5)$$

$$V_{m,r,d} \in \{0,1\} \quad \forall m,r,d \quad (T6)$$

$$Y_p \in \{0,1\} \quad \forall p \quad (T7)$$

5. Discussion

The objective (T0) measures the weighted value of (partially) completed missions. Constraints (T1) require exactly one employment schedule per ship. Constraints (T2) bound the sum of the partial completion values of all instances of a given mission, in a given region on a given day, by the total amount of activity for that mission in the region. Constraints (T3) allow a task to be considered fully completed in a region on a given day if there is at least 1.0 total units of activity for that mission in that region on that day. Constraints (T4) allow activity in mission m in region r on day d only if all prerequisite missions in that region on that day have been fully accomplished.

For an employment schedule p for ship s to represent a *feasible* set of activities over the time horizon, the values of $accomplish_{m,r,d,p}$ must satisfy the following conditions: (S1) for any day d , $\sum_m accomplish_{m,r,d,p} > 0$ for at most one region m , (S2) if $d' > d$, then $\sum_m accomplish_{m,r,d,p} > 0$ and $\sum_m accomplish_{m,r',d',p} > 0$ only if $d' - d \geq tdays_{s,r,r'} + 1$, and (S3) for any region r and day d , $\{m \mid accomplish_{m,r,d,p} > 0\}$ is a subset of some CMC for ship s . Namely, a ship can only be active in one region on a given day, it cannot appear in other regions faster than it can actually travel, and the set

of missions it accomplishes at any nonzero level is contained in some concurrent mission capability set. By convention, if a ship is not accomplishing any missions on a given day then its mission is set to ‘transit’ if it is moving between regions or to ‘off-station’ if it is staying in the same region. Table 1 displays three potential schedules for the USS Roosevelt (DDG 80) that could be considered by NMP.

What is really being solved by NMP is the problem of selecting the best employment schedule for each ship. An employment schedule for a ship is a specification by day of where it will be, what missions it will be capable of covering, and how effectively it is capable of performing each of those active mission capabilities. An employment schedule for a particular ship is feasible if a) on any day the, the set of missions accomplished on that day are in the same region, b) are a subset of CMC for that ship, and c) for any two days, the transit times between the regions the ship is in on those two days does not exceed the elapsed time between those days. If we generate feasible *complete* employment schedules for each ship, then we can write a simple model that chooses exactly one employment schedule per ship, and calculates any statistics of interest that might guide our choices. There might be thousands, (or even millions) of feasible employment schedules for each ship, but the model is greatly simplified when we develop the schedules while generating the problem data instead of relying on the model to solve for these schedules. Furthermore, if we only include a subset of feasible schedules, then we can still find a feasible solution to the mission planning problem, and if that set of schedules includes the most effective schedules for each ship then we still have a chance at finding the *optimal* set of mission assignments with this restricted model.

Ship	Arrives												
DDG80	d9												
r24		r24		r9		r9		r9		r9		r9	
AD	1	AD	1	AD	1	AD	1	AD	1	AD	1	AD	1
TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0
ASW	0	ASW	0	ASW	1	ASW	1	ASW	1	ASW	1	ASW	1
SUW	0	SUW	0	SUW	1	SUW	1	SUW	1	SUW	1	SUW	1
Strike	0	Strike	0	Strike	1	Strike	1	Strike	1	Strike	1	Strike	1
NSFS	0	NSFS	0	NSFS	0.5	NSFS	0.5	NSFS	0.5	NSFS	0.5	NSFS	0.5
MIO	0	MIO	0	MIO	0	MIO	0	MIO	0	MIO	0	MIO	0
MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0
Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0
Intel	0	Intel	0	Intel	1	Intel	1	Intel	1	Intel	1	Intel	1
Transit	0	Transit	1	Transit	0	Transit	0	Transit	0	Transit	0	Transit	0
Off	1	Off	0	Off	0	Off	0	Off	0	Off	0	Off	0
r24		r24		r15		r15		r13		r13		r14	
AD	1	AD	1	AD	1	AD	1	AD	1	AD	1	AD	1
TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0
ASW	0	ASW	0	ASW	1	ASW	0	ASW	1	ASW	1	ASW	1
SUW	0	SUW	0	SUW	1	SUW	0	SUW	1	SUW	1	SUW	1
Strike	0	Strike	0	Strike	1	Strike	0	Strike	1	Strike	1	Strike	1
NSFS	0	NSFS	0	NSFS	0.5	NSFS	0	NSFS	0.5	NSFS	0.5	NSFS	0.5
MIO	0	MIO	0	MIO	0	MIO	0	MIO	0	MIO	0	MIO	0
MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0
Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0
Intel	0	Intel	0	Intel	1	Intel	0	Intel	1	Intel	1	Intel	1
Transit	0	Transit	1	Transit	0	Transit	1	Transit	0	Transit	0	Transit	0
Off	1	Off	0	Off	0	Off	0	Off	0	Off	0	Off	0
r24		r24		r8		r8		r3		r3		r3	
AD	1	AD	1	AD	1	AD	1	AD	1	AD	1	AD	1
TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0
ASW	0	ASW	0	ASW	1	ASW	0	ASW	1	ASW	1	ASW	1
SUW	0	SUW	0	SUW	1	SUW	0	SUW	1	SUW	1	SUW	1
Strike	0	Strike	0	Strike	1	Strike	0	Strike	1	Strike	1	Strike	1
NSFS	0	NSFS	0	NSFS	0.5	NSFS	0	NSFS	0.5	NSFS	0.5	NSFS	0.5
MIO	0	MIO	0	MIO	0	MIO	0	MIO	0	MIO	0	MIO	0
MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0
Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0
Intel	0	Intel	0	Intel	1	Intel	0	Intel	1	Intel	1	Intel	1
Transit	0	Transit	1	Transit	0	Transit	1	Transit	0	Transit	0	Transit	0
Off	1	Off	0	Off	0	Off	0	Off	0	Off	0	Off	0

Table 1. Example employment schedules for the USS Roosevelt with user defined effectiveness levels for active mission capabilities

6. Excel Interface

For this investigation into navy planning, an interface was developed using Microsoft Excel spreadsheets and Visual Basic computer language. The mission information required for NMP to execute these tasks is input into the interface. Missions are identified by region, time horizon, type and value on the 'Missions sheet. Any mission dependencies that are required are identified on the 'Mission Dependencies' sheet; these dependencies are defined region, time horizon, the dependent mission and its required mission. Through the interface, navy planners can accomplish these tasks:

1. Input missions, their priority and duration into maritime regions. Multiple missions of the same type can be entered into the same region if necessary. These

values are what NMP considers when it determines the appropriate employment schedule for each ship. Table 2 displays a portion of interface's mission sheet.

Missions Determined for Regions

Region	Start Day	End Day	Mission	Values
r2	d1	d45	AD	8
r2	d1	d30	ASW	7.2
r2	d1	d20	SUW	6.6
r3	d1	d45	TBMD	10
r3	d1	d30	AD	5.5
r6	d15	d30	AD	8.5
r6	d10	d25	Strike	7
r6	d25	d35	NSFS	9
r6	d5	d20	NSFS	7
r6	d5	d20	ASW	10
r6	d5	d25	ASW	8
r6	d1	d26	Intel	6

Table 2. Missions sheet of the NMP interface

2. Define dependent missions for any region and time horizon. Certain missions may require other missions to be covered before they are undertaken. This may be because of the type of mission, the geographic location of the mission, or the type of ships that are capable of covering a certain mission type. Some U.S. Navy ship types are capable of executing some of these missions concurrently (e.g., an Arleigh Burke class destroyer could execute MIO and air defense simultaneously), but JFMCC staff planners would not want to put those ships in that position if they did not have to. NMP enables the user to define these mission dependencies. Table 3 displays the mission dependencies defined for the first six regions of the scenario.

Region	Start Day	End Day	Mission	Requires		
r1	d1	d45	MIO	AD		
r1	d1	d45	ASW	AD	SUW	
r1	d1	d45	MCM	AD	ASW	SUW
r2	d1	d45	MIO	AD		
r2	d1	d45	ASW	AD	SUW	
r2	d1	d45	TBMD	AD		
r3	d1	d25	ASW	AD	SUW	
r3	d1	d45	TBMD	AD		
r4	d1	d45	ASW	AD	SUW	
r4	d1	d45	MIO	AD		
r4	d1	d45	MCM	AD	ASW	SUW
r5	d1	d45	ASW	AD	SUW	
r5	d1	d45	MIO	AD		
r5	d1	d45	MCM	AD	ASW	SUW
r6	d1	d45	ASW	AD	SUW	
r6	d1	d45	MIO	AD		
r6	d1	d45	MCM	AD	ASW	SUW

Table 3. Mission Dependencies in the NMP interface.

3. Determine which ships to include or exclude for particular runs of the model. The available ships are listed by hull number along with their arrival day and initial location in theater. This is done in the 'Ship' sheet of the interface. Changes to the available ships can assist the JFMCC staff in the multiple COA development.
4. Determine the time horizon
5. Determine the maximum number of missions a ship can execute concurrently.

The required ship information is also input into the interface. The available ships are listed by hull number along with their arrival day and initial location in theater. Ship capabilities have been determined by class, as well as a ship's CMCs. Each CMC is a set of capabilities that a particular ship can cover simultaneously. They are critical to building feasible employment schedules. CMCs were developed for Ticonderoga class cruisers (CG), Arleigh Burke class destroyers (DDG), Oliver Hazard Perry class frigates

(FFG), Littoral Combat ships (LCS), Los Angeles class attack submarines (SSN), Ohio class guided missile submarines (SSGN) and Avenger class mine counter measure ships (MCM). With the CMCs developed, an NMP user can define the effectiveness ratios for active missions in a particular CMC set. Table 4 shows the destroyer portion of the ship availability list in the interface. Table 5 displays the CMCs for destroyers with user defined levels of effectiveness for active capabilities in each CMC.

Ship	Name	Start Day	Start Region	CMCs					
DDG53	John Paul Jones	1	9	C7	C8	C9	C10	C11	C12
DDG62	Fitzgerald	1	15	C7	C8	C9	C10	C11	C12
DDG86	Shoup	3	24	C7	C8	C9	C10	C11	
DDG90	Chaffee	4	24	C7	C8	C9	C10	C11	
DDG100	Kidd	5	24	C7	C8	C9	C10	C11	
DDG80	Roosevelt	9	24	C7	C8	C9	C10	C11	

Table 4. Destroyer portion of the available ship list from the NMP interface

	C7		C8		C9		C10		C11		C12
AD	1	AD	1	AD	1	AD	1	AD	1	AD	0
TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	0	TBMD	1
ASW	1	ASW	0	ASW	1	ASW	0	ASW	0	ASW	0
SUW	1	SUW	1	SUW	0.7	SUW	0	SUW	0	SUW	0.5
Strike	1	Strike	1	Strike	1	Strike	0	Strike	0	Strike	1
NSFS	0.5	NSFS	0	NSFS	1	NSFS	0	NSFS	0	NSFS	0.4
MIO	0	MIO	0.7	MIO	0	MIO	0	MIO	0	MIO	0
MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0
Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0
Intel	1	Intel	1	Intel	1	Intel	0	Intel	0	Intel	1
Transit	0	Transit	0	Transit	0	Transit	1	Transit	0	Transit	0
Off	0	Off	0	Off	0	Off	0	Off	1	Off	0

Table 5. Concurrent mission capable sets for destroyers from the NMP interface

The key to making the NMP a simple and effective decision aid are the ship schedules. With schedules available for each ship that take into account location, transit time and capabilities, NMP will select a schedule for each ship that maximizes the value of the missions covered by all the participating ships. Up to eleven ships were utilized in the test scenarios for this thesis. Five schedules were developed for each ship, and each

schedule was comprised of one CMC per day. Different schedules for a ship have it going to different regions, utilizing different CMCs, or both.

Figure 3 displays the main dashboard of the NMP interface. With the controls on the dashboard users can define the total time horizon for an operation, and they can also what part of the operation they want to focus on by identifying the first and last day of the planning time horizon. Users can also limit the number of like missions per region as well. When 'Solve' is clicked, NMP quickly considers all missions to identify those that are active during the specified planning horizon, identifies any user defined mission dependencies, and then determines what the best schedule for each available ship. Figure 3 displays the dashboard of the interface.

Navy Mission Planner v. 1.10	070820		
Scenario Options		Build	
Maximum Time Horizon (days)	45		
Planning Horizon First Day	5	Status	
Planning Horizon Last Day	15		
Max mission copies per (region,day)	4	Solve	
Solver Options			
Optimality criterion	0.1		
Max solve time (secs)	1800		
Solver	CPLEX		
Given schedules are	only ones considered		

Figure 3. This is the dashboard of NMP interface. We see that the planning horizon is set for 45 days; the model will only plan for days 5-15.

7. Summary

We have defined the NMP model. NMP seeks to maximize the reward value of the covered maritime missions. By defining the problem as a scheduling problem, we have simplified the math computational complexity significantly.

IV. COMPUTATIONAL RESULTS

To test NMP to ascertain if it can be a viable decision aid for naval staff officers, multiple runs conducted for a scenario involving up to eleven U.S. Navy surface ships and submarines. All computations are carried out on a 3.72 GHz Xeon Dell desktop computer at the Naval Postgraduate School.

A. TEST SCENARIO

We use as a continuing example in this thesis a notional unclassified 15 day plan of operations around the Korean peninsula. We propose a list of missions that could reasonably be expected to arise in such an operation, and provide a list of ships and their individual abilities that are intended to roughly represent our current naval capability. The seas around the Korean peninsula are divided into 24 user defined *regions*. There are 65 separate maritime missions identified in the theater. A region may have multiple missions of like or different types (e.g., region r2 may have two ASW missions identified). Multiple like missions in the same region require a different ship to cover each copy of that particular type of mission in order to get credit for covering all of them. So, if only one NSFS mission is covered in r6 then only the highest value copy of NSFS would be covered. Figure 4 shows the Korean maritime theater divided into geographic regions for our planning purposes. Table 4 displays the missions identified for the first six regions of the scenario.

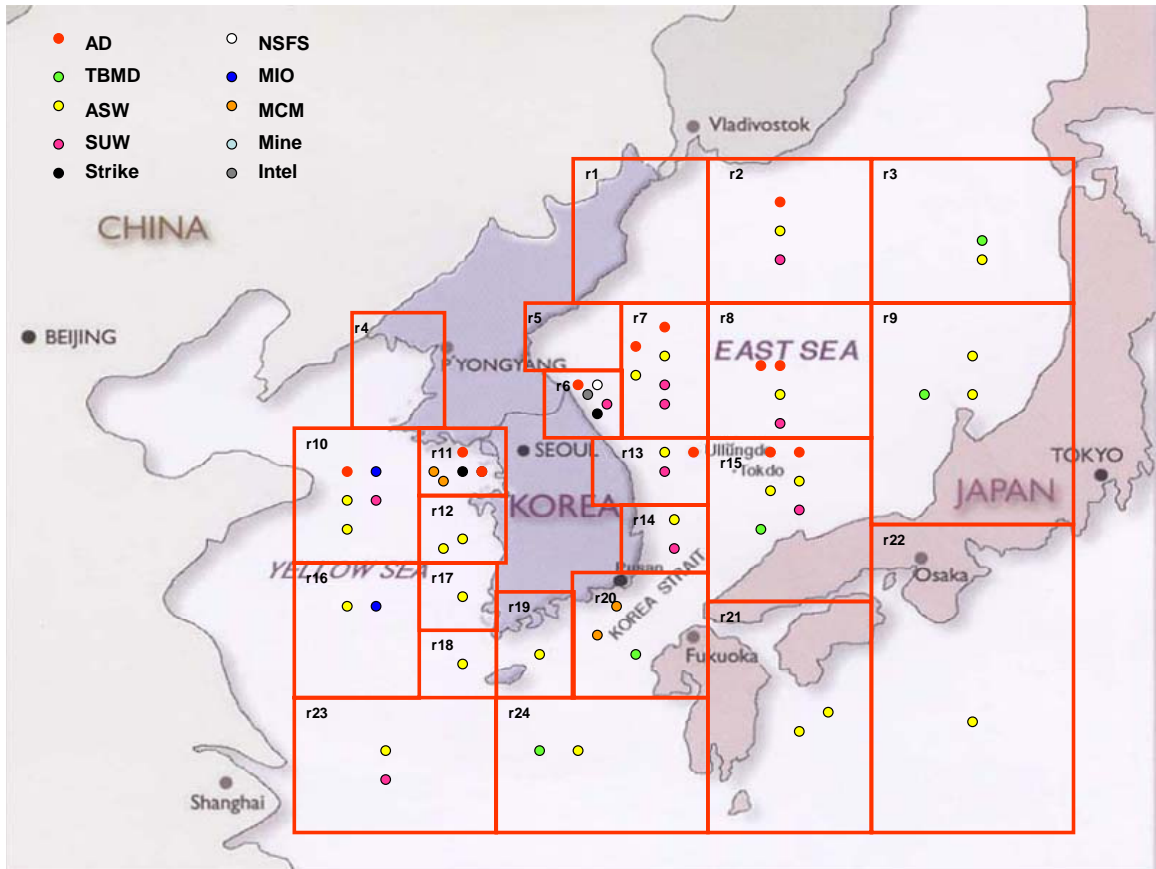


Figure 4. Chart of the Korean maritime theater with user defined regions and maritime missions. The missions displayed are aggregated for the entire time horizon.
Map source: University of Texas [2007], modified by the author.

B. TEST RESULTS FOR NMP

Testing focused on days 5 through 15 for the scenario. NMP produces near instantaneous results that are displayed in log file produced for each run of the model. NMPs speed would give FOPS or the OAC the opportunity to generate several alternative courses of action almost immediately. Effort could be spent analyzing several COAs instead of manually producing one or two of them which may not be scrutinized due to a lack of time. For example, assume the initial solution disregards a TBMD mission because NMP determined more value can be achieved by assigning TBMD capable platforms to other missions. The JFMCC staff can ensure a particular TBMD mission is covered by increasing its value. All missions were initially valued on a scale from 1 to

10 for the test scenario. TBMD mission values were increased from 10 to 25 in region nine and from 10 to 16 for region fifteen in order to get NMP to select TBMD schedules for the USS John Paul Jones and the USS Fitzgerald. These alternatives were produced almost instantly.

Table 6 shows the NMP selected schedule for the USS John Paul Jones. Table 7 displays the mission accomplishment information for day 5 of the scenario.

DDG53 Arrives:		day 1									
day 5		day 6		Day 7		day 8		day 9		day 10	
region 9		r9		r9		r9		r9		r9	
AD	0	AD	1	AD	0	AD	0	AD	0	AD	0
TBMD	1	TBMD	0	TBMD	1	TBMD	1	TBMD	1	TBMD	1
ASW	0	ASW	0	ASW	0	ASW	0	ASW	0	ASW	0
SUW	0.5	SUW	0	SUW	0.5	SUW	0.5	SUW	0.5	SUW	0.5
Strike	1	Strike	0	Strike	1	Strike	1	Strike	1	Strike	1
NSFS	0.4	NSFS	0	NSFS	0.4	NSFS	0.4	NSFS	0.4	NSFS	0.4
MIO	0	MIO	0	MIO	0	MIO	0	MIO	0	MIO	0
MCM	0	MCM	0	MCM	0	MCM	0	MCM	0	MCM	0
Mine	0	Mine	0	Mine	0	Mine	0	Mine	0	Mine	0
Intel	1	Intel	0	Intel	1	Intel	1	Intel	1	Intel	1
Transit	0	Transit	0	Transit	0	Transit	0	Transit	0	Transit	0
Off	0	Off	1	Off	0	Off	0	Off	0	Off	0
day 11		day 12		day 13		day 14		day 15			
r9		r9		r9		r9		r9			
AD	0	AD	0	AD	0	AD	0	AD	0		
TBMD	1	TBMD	1	TBMD	1	TBMD	1	TBMD	1		
ASW	0	ASW	0	ASW	0	ASW	0	ASW	0		
SUW	0.5	SUW	0.5	SUW	0.5	SUW	0.5	SUW	0.5		
Strike	1	Strike	1	Strike	1	Strike	1	Strike	1		
NSFS	0.4	NSFS	0.4	NSFS	0.4	NSFS	0.4	NSFS	0.4		
MIO	0	MIO	0	MIO	0	MIO	0	MIO	0		
MCM	0	MCM	0	MCM	0	MCM	0	MCM	0		
Mine	0	Mine	0	Mine	0	Mine	0	Mine	0		
Intel	1	Intel	1	Intel	1	Intel	1	Intel	1		
Transit	0	Transit	0	Transit	0	Transit	0	Transit	0		
Off	0	Off	0	Off	0	Off	0	Off	0		

Table 6. Selected Schedule for DDG 53 (USS John Paul Jones) for days 5 through 15. Active capabilities have been set at user defined levels of effectiveness. For example, for day 9 DDG 53 capable of covering TBMD, strike and intel with complete effectiveness, SUW at 50% effectiveness, and NSFS at 40% effectiveness.

V. CONCLUSIONS AND RECOMMENDATIONS

A. SUMMARY

This thesis has described NMP (Navy Mission Planner), an automated decision aid for the JFMCC for Navy ship schedule selection. NMP comprises a set-partitioning optimization model, and exact solver and an Excel based interface. We show that NMP is an effective tool for making optimal schedule selections for multiple ships employed in a maritime theater. NMP provides the ability to provide multiple courses of action almost immediately, and would free up a significant amount of time for FOPS and OAC personnel to critically analyze COAs for the JFMCC.

B. DIRECT OPERATIONAL APPLICATION

Recent operations like Operation Enduring Freedom and Operation Iraqi Freedom saw significant numbers of Navy combatants operate in the Arabian Sea and the Arabian Gulf. The number Navy ships in the area led to complex employment problems that the JFMCC and 5th Fleet had to address. Their performance has been successful, but what they have accomplished has been a manual effort without the aid of an analytical decision aid. This thesis describes and demonstrates an automated decision, NMP, which will greatly increase the efficiency and effectiveness of Navy staffs like these.

C. OPERATIONAL INTRODUCTION

As originators of the request to develop NMP, the Naval Warfare Development Command and the Naval War College are planned to receive briefings in the near future. The next steps include interactive training with operational planners to improve the model and the interface.

D. FUTURE DEVELOPMENT

After introducing NMP to a number of naval and staff planning subject matter experts, we recommend the following suggestions are made to make NMP more useful to the fleet and to the other services.

1. Interface with the Common Operating Picture (TBMCS)

NMP should interface with current common operating picture (COP) software. While utilizing rolling time horizons, the JFMCC staff could utilize the live updates for ship location, remaining weapons, ship readiness and training levels and other important information in order to base plans off the most current and relevant operations information. The current system is known as Theater Battle Management Core System (TBMCS) and its successor, currently in development, is the Joint Battle Management Command and Control (JBMC2).

2. Utilize NMP logic to Plan Fire Support

The set partitioning logic of NMP could be effectively utilized to by a JFCs staff to employ joint fires assets. Planned fires could be determined efficiently by a model that takes into account the capabilities and location of towed artillery batteries, self propelled artillery batteries, Multiple Rocket Launcher Systems (MLRS) and tactical aviation attack assets. Joint fires currently rely on aviation to conduct the vast majority of its missions. A decision aid designed along lines similar to the NMP could provide more possibilities for joint fire planners.

3. Utilize NMP logic to Focus Marine Corps Distributed Operations Concept

The complex modern battlefield, with multiple missions dispersed over long distances, poses complex problems for today's soldiers and marines. The Marine Corps has started to explore a concept, known as *distributed operations*, to answer this predicament. One of the principles of distributed operations is employment of independent small units, which could be infantry companies, platoons, squads, or even as

small as a four man fire team. Small task organized units will operate throughout the distant modern battlefield. An NMP like tool could assist the Marine Corps' continuing development of distributed operations by matching missions to the appropriately task organized combat or support unit.

4. Constrained Enumeration of Feasible Employment Schedules

NMP requires a schedule enumeration package in order to maximize its usefulness to navy planners. We postulate that, without any exogenous guidance, this enumeration could quickly run into millions (or billions) of feasible schedules per ship. However, many of these "feasible" employment schedules will be completely impractical (for example, a schedule in which the ship under consideration is in 'transit' or 'off-station' mode for all, or even most, days in the time horizon), and can be safely ignored. With a few simple controls, such as limiting total number of regions visited per schedule, or limiting the total number of days in 'transit,' we could reasonably limit the number of schedules enumerated without sacrificing solution quality.

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Camp Pendleton, California
7. Naval War College (Attn: JFMCC Planning Instructors) Newport, Rhode Island
8. Naval Warfare Development Command (Attn: Operations Section) Newport,
Rhode Island